SPECTROSCOPIC INVESTIGATIONS OF SOME ISOTOPES IN THE NUCLEAR LEAD REGION

Construction of a Beta-Ray Spectrometer

by

EDVIN ARBMAN

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ALMQVIST & WIKSELLS BOKTRYCKERI AB

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INAUGURAL DISSERTATION

by

EDVIN ARBMAN

FIL. LIC., SMÅL.

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OF THE UNIVERSITY OF UPPSALA TO BE PUBLICLY DISCUSSED
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The present investigations concern the decay of nuclei in the neighbourhood of the double magic number Pb^{208} nucleus. Low-lying excited energy states of odd mass nuclei in this region can often be identified with states occupied by the odd nucleon in agreement with the predictions of the strong spin-orbit coupling shell model. In particular the presence of one-particle levels in accordance with the shell model are manifested in the occurrence of isomers in nuclei where the protons and neutrons are filling up the closed shells of 82 and 126 nucleons respectively.

The shell model has been extended in an important manner by the calculation of levels resulting from the coupling of two or more nucleons (or holes) outside the core of closed shells, each extra particle being assigned a single-particle state, as was first attempted in the lead region by Pryce in 1952. Such calculations are in practice limited to nuclei differing by only a few nucleons from the double-closed shells. Later extensive experimental and theoretical studies of the energy levels of some lead isotopes (e.g. Pb^{206}, Pb^{205} and Pb^{204}) have been performed at various institutes. Especially the detailed investigations of Pb^{205} have resulted in good agreement between experiments and theoretical calculations.

The spectroscopic measurements deal with two problems:

1. Investigation of the decay of and search for isomers in neutron-deficient isotopes of lead and thallium.

2. Studies of excited energy levels in Bi^{207} and Bi^{206}. These nuclei differ from the double magic Pb^{208} nucleus by three and four nucleons respectively and an investigation of their energy levels was considered to be of interest. A theoretical study of the levels in these nuclei has been made by Wahlborn.

The experiments are described in the following articles and will be summarized below.

I. E. Arbman and N. Svartholm, A high transmission beta-ray spectrometer of the double focusing type. Arkiv för Fysik *10*, 1 (1955).

II. Göran Andersson, Edvin Arbman and Bo Jung, Lead and thallium isotopes in the mass range 195–199. Arkiv för Fysik *11*, 297 (1956).

III. E. Arbman, J. Burde and T. R. Gerholm, Energy levels in Bi^{207} from the decay of Po^{207}. Arkiv för Fysik *13*, 501 (1958).

IV. E. Arbman, Excited levels in Bi^{206} from the decay of Po^{206}. Nuclear Physics *3*, 625 (1957).

V. E. Arbman and P. A. Tove, Isomeric state in Bi^{206}. Arkiv för Fysik *13*, 61 (1957).

In the nuclear region concerned the radioactive decays are in general rather complex. Instruments with high resolution are therefore of considerable value in the study of the emitted radiation. The construction and performance of a small double focusing beta-ray spectrometer, which has been used for the investigation of the electron and positron spectra in this work, is described in (I). The $B\varrho$ value, proportional to the electron momentum, is determined as a function of the current through the spectrometer coils; the current being accurately measured by a compensation method. A calibration curve is given for the $B\varrho$ range 400 to 20000 gauss cm. The accuracy in $B\varrho$ obtained from this curve is about 0.1 %.

For more accurate energy measurements the ratio of $B\varrho$ to current is conveniently plotted versus current on a semilogarithmic scale, in which case an almost straight line results for $B\varrho$ less than about 4500 gauss cm (cf. the figure).

By the use of appropriate calibration lines accurate energy measurements are thus possible, the error limits being largely set by the uncertainties in the line positioning and the errors in the $B\varrho$ values of the reference lines.

The spectrometer is provided with an arrangement for automatic recording of spectra which was of special applicability in the investigation of the neutron-deficient lead and thallium isotopes reported in (II). The presence of mixtures of isotopes in the spectrometer sources and the short half-lives prevented detailed studies of the spectra to be made. However, the investigation led to the discovery of 12.2 min Pb^{199m}, 2.4 hr Pb^{198}, 42 min Pb^{197m}, 37 min Pb^{196}, 17 min Pb^{195m}, 2.7 hr Tl^{197}, 2.4 hr Tl^{196} [1] and 1.2 hr Tl^{195}. Mass assignments were made with the aid of an electromagnetic isotope separator.

Fragmentary decay schemes, partly supported by electron-electron coincidence measurements, are proposed for the isotopes of odd mass numbers, and a comparison is made of the decay of these isotopes with the known decays of other odd mass-number lead and thallium isotopes.

(III) deals with the investigation of the energy levels in Bi^{207}. A detailed description is given of the various measurements performed and the treatment and analysis of data. The experiments include: Accurate measurements of energies and intensities of conversion lines and positron spectra; measurements of gamma-ray spectra;

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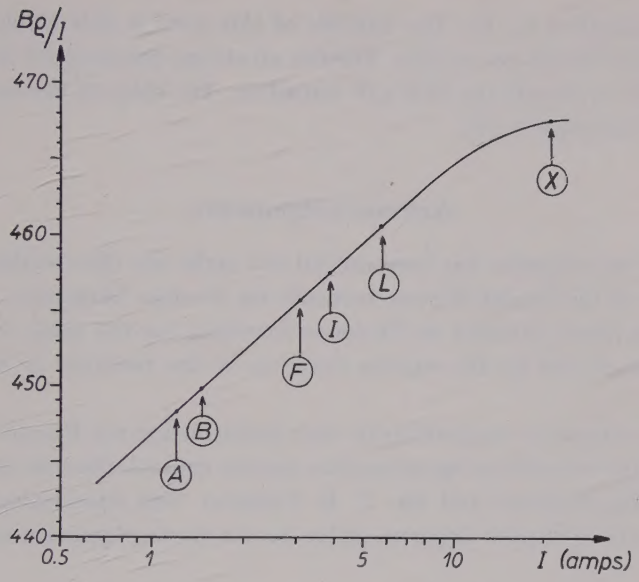
[1] Using mass-separated sources the half-life of Tl^{196} has recently been remeasured as 1.8 ± 0.1 hr [G. Andersson, J. O. Burgman and B. Jung, Phil. Mag. *3*, 105 (1958)]. The erroneous value reported in (II) was caused by conversion lines of Tl^{197} coinciding with the lines of the 425 keV transition in Tl^{196}, used for the half-life measurement. The remeasured K/L ratio of the 425 keV transition is 2.75 ± 0.28.



Calibration curve for the spectrometer drawn on semilogarithmic scale (cf. Fig. 9 in paper I). The points are the measured values for the A, B, F, I, L and X lines from the decay of ThB and its descendants.

measurements of coincidences between pairs of conversion lines, between positrons and conversion lines, and between positrons and gamma-rays.

The decay scheme of Po^{207} constructed on the basis of the experimental results is in quantitative agreement with the analysed coincidence data. Two excited levels were found to be fed by positrons, the presence of which enabled the total decay energy of Po^{207} to be deduced. Intensities and multipolarities are derived for all the intense transitions and spins and parities are assigned to the most strongly populated levels in Bi^{207} and the ground state of Po^{207}. Information is further obtained of the log ft values in the electron capture and positron decays.

In (III) also the decay of Po^{207} is discussed on the basis of the shell model, and the spins and energies of the observed levels in Bi^{207} are compared with the values for theoretically predicted levels.

Though the conditions for producing strong activities seemed more favourable for Po^{207} than for Po^{206} it was found convenient to start the study of the level schemes of the Bi isotopes with an investigation of the decay of Po^{206}. The experiments on the energy levels in Bi^{206} are reported in (IV). Here the method used for the preparation of spectrometer sources is also described. The proposed decay scheme of Po^{206} contains 9 excited levels, the lowest one assumed to be de-excited by an intense $E2$ transition of 59.9 keV energy.

The presence of the low-lying 59.9 keV level in Bi^{206} is definitely established by the

experiments described in (V). The half-life of this level is determined as 7.8 ± 0.3 μsec by delayed coincidence studies. Further all strong gamma-rays in the decay of Po^{206} are found to precede the 59.9 keV transition. The spins of the excited levels in Bi^{206} are also discussed in (V).

Acknowledgements

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Edvin Arbman